Neuromagnetic activity was enhanced by reward-related visual stimulus

H. Ishikawa[1], T. Imada[2,3], and M.Tojo[1]

[1]*Senshu University, School of Literature, Department of Psychology, Kawasaki 214-8580, Japan;* [2]*NTT Communication Science Laboratories, Nippon Telegraph and Telephone Corporation, Atsugi 243-0198, Japan;* [3]*Real World Computing Partnership, Atsugi 243-0198, Japan*

1 Introduction

When we play sports game, many brain regions are activated including the motor area, the language area, probably the frontal area to think strategies, etc. This is also true when we enjoy TV game by moving some fingers. How about when we are doing gamble, such as roulette? In playing the roulette, we have to think which number and color we should bet, and we have to estimate the results to think the next strategy. All these behaviors activate some brain regions, or more correctly the activity in some brain regions produces these behaviors. However, if the reward is related like the above roulette, which brain regions are activated when we win or lose the game? "Win" means the reward, and "lose" means no reward. Thus, we are interested in which brain regions are activated when the subjects estimate the outcome of their game including "reward."

The purpose of the present neuromagnetic study is to find the brain regions related to the estimation of "win" and "lose" in the game including some reward.

2 Materials and methods

2.1 Subjects and recording

We studied nine healthy right-handed Japanese student volunteers (6 males; 21-24 years old). Brain magnetic fields were recorded by a whole-scalp neuromagnetometer (Neuromag-122, Neuromag Ltd., Finland) in a magnetically shielded room (Model MSR4B, Amuneal Manufacturing Corp., USA).

2.2 Stimulus

A visual stimulus, subtending 2.4° in height and 1.8° in width, included a number and a symbol similar to a playing card as shown in Fig. 1.

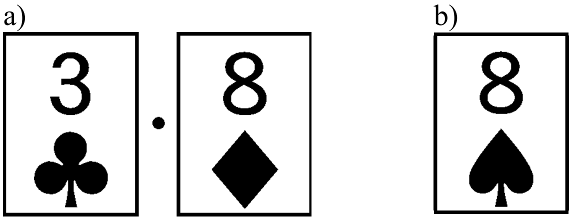

Figure 1: *Examples of stimuli: a) An example of Problem stimuli. The central black point is a fixation point. b) An example of Dummy stimuli or Reward-related stimuli.*

In one epoch, 3 stimuli, Problem stimulus, Dummy stimulus, and Reward-related stimulus, were successively presented in this order one at a time on a screen with the distance of 45 cm from the subject's eye. The Problem stimulus included two stimulus cards, which were presented 2.0° to the left and right of a fixation point (Fig.1-a). The Dummy stimulus and the Reward-related stimulus included one stimulus card, which was presented on the fixation point (Fig.1-b). For each Problem stimulus, 3 series of Dummy and Reward-related stimuli were prepared. By showing their index, middle or ring finger to the experimenter, the subjects selected one of these 3 choices, which determined the stimulus to be presented after the Problem stimulus. The subjects did not know which number and symbol were included in the next coming Dummy and Reward-related stimuli when they selected. The time course of the Problem, Dummy, and Reward-related stimuli and the subject's selection are described in Fig. 2.

An interval between two adjacent epochs was random between 1500ms and 1700ms.

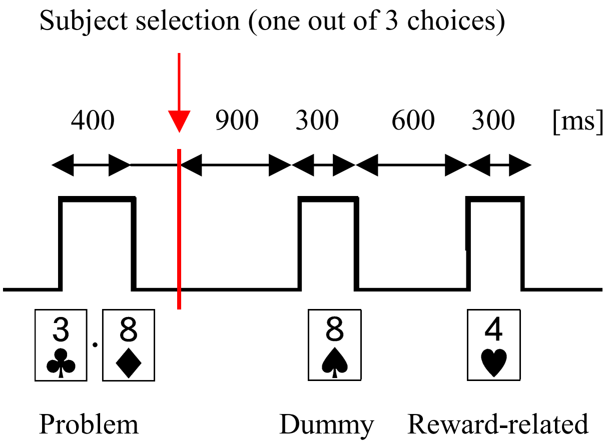

Figure 2: *Time course of the Problem, Dummy, and Reward-related stimuli, and the subject's selection.*

2.3 Subject's task

The subjects were instructed to select the next coming two cards, namely the Dummy and Reward-related stimuli, out of 3 choices after the Problem stimulus was presented. Only one of these 3 choices always gave "win" to the subjects, and the other two did not. The subject got "win" if the number in the Reward-related stimulus card was between the two numbers shown in the Problem stimulus, and got "lose" if the number in the Reward-related stimulus card did not exist between the two numbers shown in the Problem stimulus. The stimulus card symbol was irrelevant. The final goal for the subject was to get the highest "win" rate to obtain the reward. The "win" rate was defined as the number of "win" epochs divided by the sum of "win" and "lose" epochs. We instructed the subjects that the one who marked the highest "win" rate among all subjects would acquire the reward.

The expected mean "win" rate was about 0.33 if the subjects randomly determined their choice because there was only one "win" card out of 3 choices. However, before the experiment, the subject was informed that there were 8 rules for the sequence of "win" choices. For example, in one rule, the win sequence includes "choice-1, choice-2, choice-3, choice-1, choice-2, choice-3, …" This means that the subjects win every epoch when they realize the rule and select these choices in this order. In another rule, the win sequence includes "choice-3, choice-1, choice-2, choice-3, choice-1, choice-2, …" Therefore, by guessing correctly the present rule, the subjects could increase their "win" rate. However, if the "win" rate of the latest 10 epochs reached 0.8, the experimenter selected another rule.

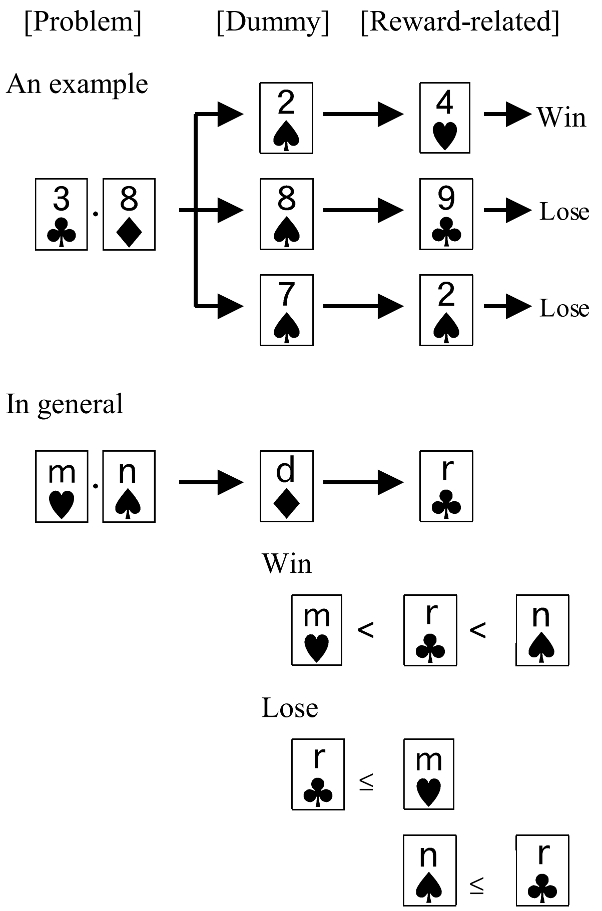

Figure 3: *"Win" and "lose": a) If the subject selects the choice-1 that will present a "4" heart card, the subject will win because the "4" is between 3 and 8 that are presented in the Problem cards. b) In general, suppose that the subject selects the choice-k (k=1, 2, or 3) that will present a "r" card as the Reward-related card. If* $m < r < n$*, where "m" and "n" are the numbers presented in the Problem cards, the subject will win. However, if* $r \le m$ *or* $n \le r$*, the subject will lose.*

2.4 Data processing

The signals were first analog-filtered between 0.03 and 100 Hz and then digitized at 0.5 kHz. Any epoch with vertical or horizontal electro-oculogram (EOG) exceeding 150 μV or with MEG signals beyond 3000 fT/cm was rejected.

More than 80 responses were averaged separately for the "dummy," "win," and "lose" conditions.

2.5 Analysis

The averaged signals were digitally lowpass-filtered at 40 Hz, and then the DC-offset during 100-ms pre-stimulus baseline was removed.

The analysis time was 900 ms from 100 ms prior to the stimulus onset. The grand mean waveforms averaged across subjects were calculated after virtually shifting each subject's head position and orientation to the standard position and orientation.

Equivalent current dipoles (ECDs) were localized by the revised local channel method [1].

The activity, defined here as the active latency length of the ECD clusters obtained by the above procedure, was calculated in each of 28 brain regions of interest in each hemisphere.

We performed the following three repeated measure analysis of variance (ANOVA) in each brain region.

a) Two-way ANOVA (hemisphere x outcome) examined the difference between the hemispheres and between the game outcomes, namely “win” and “lose.”

b) Two-way ANOVA (hemisphere x lose-game) examined the difference between the hemispheres and between the lose-game and the control (the responses to the irrelevant Dummy card).

c) Two-way ANOVA (hemisphere x win-game) examined the difference between the hemispheres and between the win-game and the control.

2 Results

3.1 Behavioral data

The mean win rate was 49±0.05% and the maximum win rate was 58%.

3.2 Neuromagnetic data

In the analyses of activity, 4 out of 9 subjects were outliers of 95% confidence interval in any one or more brain regions of interest, and thus the data from these 4 subjects were eliminated from further analyses. Figure 4 describes the grand mean waveforms across the remained 5 subjects. The waveforms show the larger and longer activity in "win" responses than in "Dummy" responses in the parietal area as shown in the insets. Figure 5 illustrates typical examples of ECD locations obtained from "win" responses.

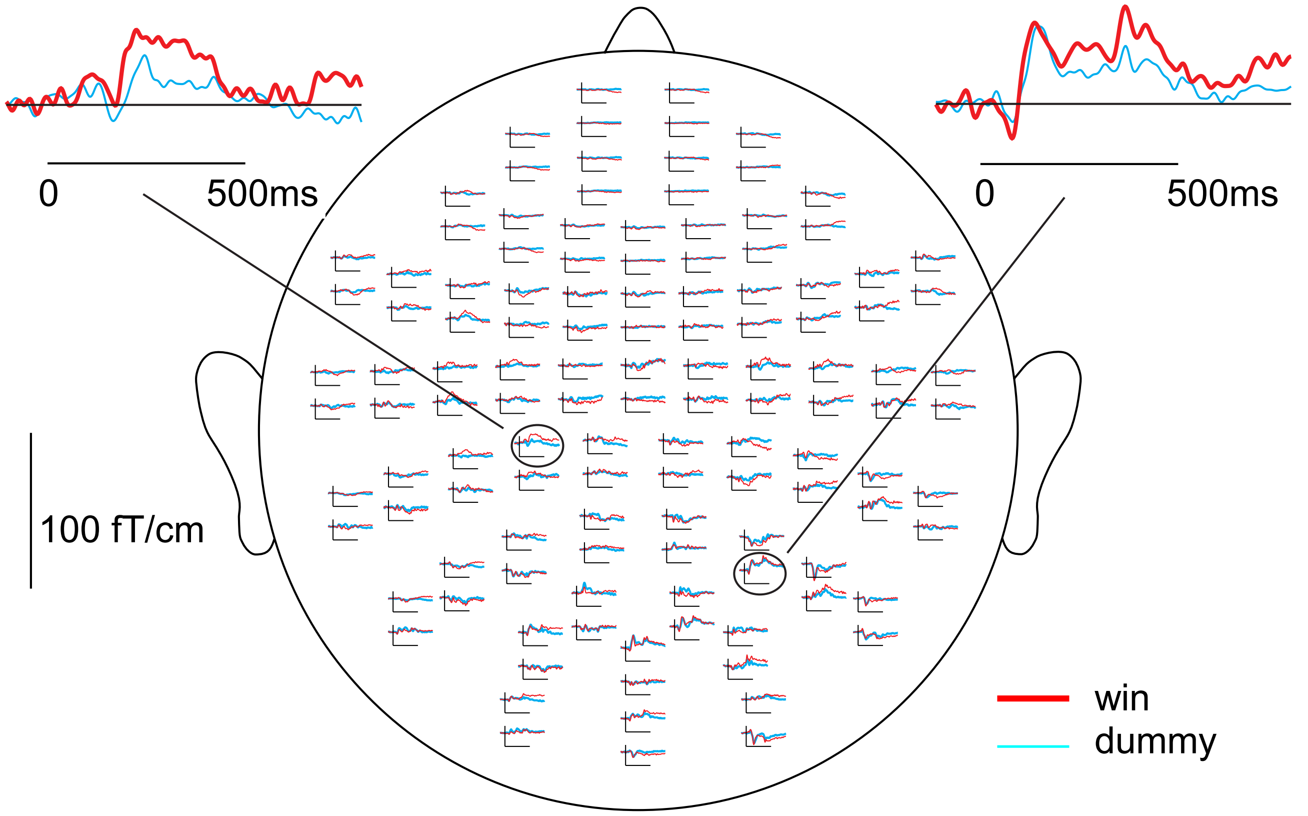

Figure 4: *Waveforms [Grand mean across 5 subjects] in response to “win” stimulus (thick) and to "Dummy" stimulus (thin). The responses over the left and the right angular regions are enlarged in the left and the right insets, respectively. The stimulus was exposed from 0 to 100 ms.*

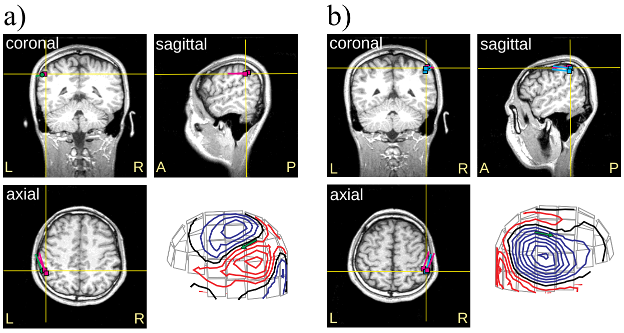

Figure 5: *Typical ECD clusters in response to the "win" stimulus projected onto the subject's own magnetic resonance images. Several ECD clusters that are included in the same brain region are depicted at the cross point of white vertical and horizontal hair lines together with the corresponding contour maps. "L" means the left, "R" the right, "A" the anterior, and "P" the posterior side of the head. a) The ECD clusters localized in the left angular region. b) The ECD clusters localized in the right angular region.*

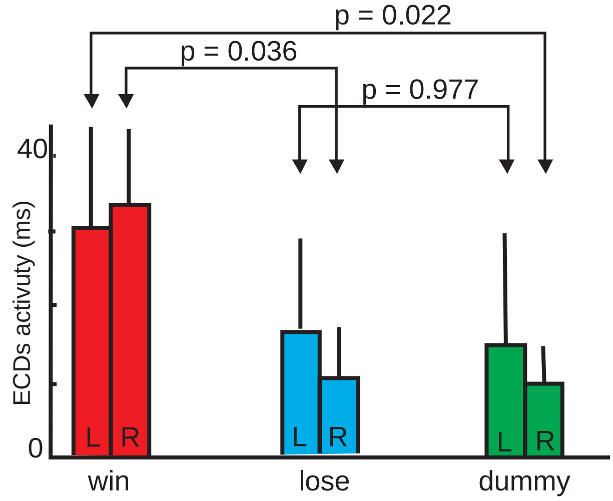

Figure 6: *Left panel shows the activity in the left (L) and right (R) angular region for the "win" response, middle panel for the "lose" response, and right panel for the "dummy" response. Significant differences were obtained both between "win" and "lose" responses and between "win" and "dummy" responses.*

The first ANOVA-a showed significant main effect of "outcome" only in the angular regions, stating that the "win" response was significantly larger than the "lose" response in the angular region (F (1, 4) =9.59, P = 0.036). The second ANOVA-b did not show any significant main effect in all brain regions. The third ANOVA-c showed significant main effect of "win-game" only in the angular regions, stating that the "win" response was significantly larger than the "dummy" response (F (1, 4) = 13.17, P = 0.022).

4 Discussions

The activity in the angular region seems to be involved in the processing of the "win" game because the activity in the angular region was significantly larger when the subject won the game.

In our experiment, the subject had to process the numbers to judge the game outcome. It may be possible that the activity in the angular region was related to this number processing. This is true for the comparison between "win" and "dummy" responses because the number processing is not necessary for the "dummy" stimulus. However, this is not the case for the comparison between the "win" and "lose" responses because the subject had to process the numbers even for the "lose" responses. Thus, we suggest that the larger activity in the angular region is not related to the number processing.

In our experiment, the subject had to find the rule governing the stimulus presentation as well as to estimate the game outcome. It may be possible that the activity to find the rules may be performed in the angular region. However, considering that the activity to find the rules surely comes after the estimation of game outcome, that it comes stronger before the subject selects the choices, and that it might be stronger after the "lose" stimulus than after the "win" stimulus, we suggest that the activity in the angular region may not be strongly related to this activity to find the rules.

In our experiment, the subject who gained the highest win rate can get the reward, and thus the activity in the angular region may be related to the reward.

Reference

1. T. Imada, T. Mashiko, and H. Sekine, "Estimation errors of single dipole model applied to twin dipole activity." This volume.